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ELECTRONICALLY CONTROLLED TORQUE MANAGEMENT SYSTEM FOR THREADED FASTENING

FIELD OF THE INVENTION

The present invention relates to tools for threaded fasteners generally, and more specifically
5 to automated and semi-automated tools for applying a predetermined torque to a threaded fastener.

DESCRIPTION OF THE RELATED ART

Threaded fasteners are commonly tightened with impact tools. An example of a field in
which impact tools are used extensively is the automotive service market, in which impact tools are
used for the reapplication of automotive wheels. Although impact tools are not designed to
10 accurately control torque, many tire shops use impact tools as the primary means to re-apply lug nuts
when mounting tires on automobiles. The current best practice in the industry includes re-applying
the wheel lug nuts with an impact tool that has a torque stick attached to the output shaft and then
hand tightening the nut 130 with a hand torque wrench to verify torque. Torque sticks are designed
to limit the maximum torque that an impact tool can apply to a nut 130, however, the actual torque
15 achieved is determined by the impact wrench, air pressure, joint stiffness, and joint condition.
Torque sticks only limit the torque applied; they do not allow the operator to specify a target torque,
and there is no verification of the final joint torque. The two-step process of using an impact tool
and then a torque wrench is also time consuming.

Tire shops have many different policies and procedures in place to attempt to improve
20 quality, however, all the procedures rely heavily on the skill and desire of the operator to perform the
required steps. It is difficult for the tire shops to enforce their policies one hundred percent of the
time, because a mechanic can complete the job using other available tools without following the
proper procedure, and without applying the correct torque. Over or under tightening lug nuts can
damage the wheel, hub and brake assembly. Damage to the wheel components can impact safety.
25 Improperly tightened wheel lug nuts can potentially cause wheel separation.

Automobile manufactures publish very specific torque requirements for re-applying wheels
to vehicles. Although tire shops may attempt to meet these specifications, their policies and
procedures may not ensure detection of situations in which the lug nuts are tightened to an improper
torque or not tightened at all. Several commercially available systems attempt to control the torque
30 output of either an impact tool or a pulse tool.

SUMMARY OF THE INVENTION

The present invention is a system for managing a regulator that controls an amount of power supplied to a tool. At least one controller controls the regulator so as to supply an amount of power to the tool to apply a predetermined torque to each of a plurality of fasteners sequentially. A processor, separate and distinct from the controller, stores data including an identification of the plurality of fasteners and the predetermined torque to be applied to the fasteners by the tool. The processor provides the data to the at least one controller.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an exemplary system according to the invention.

FIGS. 2A-2H are flow chart diagrams showing the operation of the exemplary tool management system shown in FIG. 1.

FIGS. 3A and 3B are flow diagrams showing the operation of the exemplary data management system shown in FIG. 1.

DETAILED DESCRIPTION

The present invention is a complete torque management system that can be integrated into an automotive service shop to improve the integrity and quality of the bolted joint for automotive wheels. The system will force the operator to follow a set procedure through a sequence of electronic checks and verification.

The system includes: a regulator that limits an amount of power supplied to a tool, a tool that contains a torque transducer on the output shaft to monitor the actual torque applied to the fastener, a solenoid valve to stop the air supply to the tool when the desired torque is reached, and a controller that controls all the functions of the system. In addition to these main system components the system also contains a pressure transducer to monitor the air pressure supplied to the tool and a lubricator sensor to verify that lubricant is being supplied to the tool. The software in the system contains a "snugging" feature which requires that the operator tighten all the fasteners to a torque value lower than the final torque to insure that the wheel and hub have been properly aligned. At least one controller controls the regulator so as to limit an amount of power to the tool to apply a predetermined torque to each of a plurality of fasteners sequentially. A processor, separate and distinct from the controller, stores data including an identification of the plurality of fasteners and the predetermined torque to be applied to the fasteners by the tool. The processor provides the data to the at least one controller. All the components in the system work together to verify that the desired tightening process has been used.

The lug nut tightening systems and policies of the prior art do not provide any documented proof that every nut on every tire is tightened to the desired torque specification. An aspect of the exemplary system is a torque management system that can: tighten lug nuts to torque specifications; provide electronic storage and verification of the final torque applied to each nut; provide
5 verification that every lug nut on every wheel was tightened; detect over and under torque; detect whether a lug nut was re-tightened; help detect stripped or damaged threads; reduce operator input to prevent mistakes; force the operator to follow an accepted procedure through electronic verification and checks; interface with the shop point of sale system to allow electronic torque input based on automobile make, model, option and year and interface with the shop point of sale system to allow
10 automatic transfer and storage of data.

The exemplary torque management system 100 can be integrated into an automotive service shop to improve the integrity and quality of the bolted joints of automotive wheels. The system forces the operator to follow a set procedure through a sequence of electronic checks and verification. Additional benefits of the system are improved productivity and improved ergonomics.
15 Productivity is improved because the number of tools (steps) required to complete the tightening job is reduced from two to one and the entire job can be completed with a power tool. Ergonomics are also improved because the system will reduce re-work and hand tightening or checking of the lug nuts.

It will be understood that many of the individual components (such as, for example,
20 regulators, valves, pulse tools) of this system have been used separately in other torque control applications for many years. A detailed description of these prior art components is not provided herein, but is understood by one of ordinary skill in the art.

FIG. 1 shows an exemplary embodiment of the hardware for the torque control system 100. The two major components of the control system are:

25 (1) A Data Management System (DMS) 110 which controls the entry of work order information. Data from the Point of Sales (POS) terminal 112 in the customer service area update the DMS 110 with new work orders; and

(2) One or more Torque Management Systems (TMS) 106, each of which controls the flow of air to a corresponding tool 104 and monitors the torque being applied by the tool. The TMS
30 106 also functions as an interface for the operator providing visual and audible information on the progress of the tightening sequence.

In addition to the DMS 110 and TMS 106, the system may include a discrete energy tool 104 or similar type of tool an air supply 101, and Air Control System (ACS), which includes a regulator 103a and an electronically controlled solenoid 103b.

5 The system 100 contains a standard shop air compressor 101 that is connected by standard shop air plumbing 102 to an electro-pneumatic regulator 103a that is connected to an electrically controlled solenoid 103b. The electro-pneumatic regulator 103a and solenoid 103b are connected to a discrete energy tool 104 through a pneumatic hose 105. The electro-pneumatic regulator 103a and solenoid 103b are also connected to the Torque Management System (TMS) 106 by an electrical cable 107. The TMS 106 controls the air pressure in the system 100 by varying the voltage signal to
10 the electro-pneumatic regulator 103a. The TMS 106 is connected to a discrete energy tool 104 by an electrical cable 108. The electrical cable 108 is connected to strain gages 109 that are applied to the output shaft of the tool. The TMS 106 is connected to the Data Management System (DMS) 110 by an "Ethernet™" cable 111. The DMS 110 can then be connected into the shop point of sale (POS) system 112 by an "Ethernet™" cable 113 or the like. The DMS is also connected to a printer 114 by
15 a serial or parallel printer cable 115. The electrical control wire on each tool is also fitted with a "smart chip" 116 (memory chip that contains: tool serial number, calibration number, maintenance history, and a running total of the number of cycles run with the tool since the last calibration). The system can accommodate either a single TMS unit controlled by one DMS, or multiple TMS units controlled by one DMS.

20 The exemplary Data Management System 110 is embodied in a programmed personal computer that has a display (which may be a VGA or SVGA or the like), keyboard, hard drive and a pointing device (e.g., a mouse, track ball, stylus, etc.). The exemplary DMS 110 has a user interface, which is a custom Windows™ based application program that allows the shop supervisor to enter information for a specific job, which may include, for example, mounting two of the four tires on a
25 given automobile. The DMS 110 also contains a data file that contains the manufacturing torque specifications and number of wheel lug nuts 130 for most makes and models of automobiles.

The exemplary Torque Management System 106 is embodied in an electronic logic controller or control box that controls the flow of air to the tool by electrically controlling an electro-pneumatic regulator 103a and a solenoid valve 103b. The TMS 106 also monitors the torque being applied to
30 the joint by evaluating the signal from the strain gage 109 on the output shaft of the tool 104. The exemplary TMS 106 contains an "enter" key and "cursor" keys that allow the operator to toggle through a plurality of work orders sent to the controller from the DMS 110. The TMS 106 contains a

display, such as a 3 VGA screen 106a, to view textual and graphical output and other indicators (such as, for example, red and green LED lights 106b and 106c) to indicate successful tightening operations, as well as fastening errors.

One or more TMSs 106 are continually updated with work orders as they are entered through
5 the DMS 110. All the open work orders are queued in all the TMS controllers 106. The service technician drives the vehicle on which work is to be performed into the service bay. The technician then toggles through the list of open work orders displayed on the TMS 106, until he or she finds the correct car. The technician chooses the car from the available list and all of the information including the torque specification, number of lug nuts 130 and number of wheels 120 is downloaded
10 into the controller 106. The information on this car is removed from all other TMS controllers 106 at this time. Data such as car make, model, license plate number, torque specification, number of lugs 130 per wheel 120, and number of wheels 120 are displayed on the TMS screen 106a. Downloading the torque specifications from the DMS prevents operator error.

The TMS 106 manages the steps of the process and provides the operator with error
15 feedback and messages to assist him in completing his work order. The TMS 106 provides all necessary functions to ensure appropriate torque is applied to each nut 130 of each wheel 120. The TMS provides graphic indication to the operator as to the proper sequence in which to apply each nut 130 to the wheel 120 (the sequence, commonly referred to as the "star pattern" is required and documented in torque specifications). The TMS 106 also monitors the system air pressure to prevent
20 a malfunction in the air pressure from affecting the quality of the job. The TMS 106 also monitors the level of lubricant in the inline lubricator to verify that the tool 104 is receiving the recommended amount of oil. Lubricating the tool at a regular interval will improve performance. Any job not completed with 100% compliance of the initial job requirement, and any deviations or errors monitored by the TMS 106, triggers an alarm condition, prevents the job from progressing beyond
25 that point and provides help messages to the operator to take corrective actions.

Data Management System

The user interface of the DMS 110 is via a custom Windows™ based application program running on an IBM compatible PC, sharing resources with other applications. This interface allows the supervisor to enter information specific to the customer job.

30 The DMS contains a vehicle manufacturers' database. The vehicle manufacturers' database provides standard data for each make, model, and year including:

1. Number of lug nuts 130 for each wheel 120.

2. Automotive lug nut torque settings.
3. Type of wheels (steel or aluminum).

If a customer's vehicle is not listed in the manufacturers' database (e.g., for a new type of vehicle) or if the vehicle has aftermarket wheels, the information for that vehicle type can be entered manually at either the DMS or the TMS. Permission to enter or edit this data is password protected for safety and security reasons.

The DMS software retrieves information from the manufacturers' database to construct the TMS data set that is transmitted to each TMS 106. For each job that is submitted, the DMS adds a record to the TMS data set. This record combines the standard parameters from the manufacturers' database for the type of vehicle being worked on with customer specific inputs for that particular job.

One of ordinary skill can select a desired set of required parameters and a set of optional parameters for each job entered in the TMS data set (job list). The exemplary TMS data set requires the following information for each job record (i.e., for each vehicle serviced): Make, Model, option, Year of manufacture, and Number of wheels 120 to be serviced

Other information may optionally be provided including: Customer address, vehicle ID number (VIN), color of vehicle, shop service order number, license plate number, state or province and the like. Other configurations for the TMS data set may be implemented using various combinations of the above (and/or other) parameters.

Once, the DMS 110 creates a TMS dataset (or TMS job list), the DMS 110 dynamically updates the TMS job list. Depending on the architecture of the TMS 106, the TMS job list may be dynamically updated by replacing the whole TMS dataset, or, preferably, by sending individual job record updates to the TMS 106 as transactional updates to the TMS job list.

Torque Management System

One or more TMS's 106 are continually updated with work orders as they are entered through the DMS 110. The operator can pick, from a list on the TMS display 106a, the job assignment matching the car in his service bay. The TMS 106 manages the tool functions required to complete the selected job. After a job is selected at the TMS, the operators' number or name will be selected at the TMS to identify the individual that is responsible for completing the job. The exemplary TMS 106 is programmed to require the operator to first snug (tighten to a torque that is much less than the required final torque) the nuts 130 of the wheel 120 in place and then tighten each nut 130 of the wheel 120 to the correct final torque before moving to the next wheel. The TMS 106 manages the quality of the operation and provides the operator with error feedback and messages to

assist him in completing his work order. The TMS 106 provides all necessary functions to ensure appropriate torque is applied to each nut 130 of each wheel 120. The TMS 106 also monitors the air pressure to prevent a malfunction in the air pressure from affecting the quality of the job, oil level in the inline lubricator to insure that the tool is lubricated according to design recommendations, and tool temperature. The TMS can adjust the tightening algorithm to account for temperature effects. Any job not completed with 100% compliance of the initial job requirement and any deviations or errors monitored by the TMS 106 triggers an alarm condition, preventing the job from progressing beyond that point and provides a help message to the operator to take corrective actions.

The exemplary TMS controller 106 is based on the Ingersoll-Rand Controller Platform. It uses the ARM 720 controller with Ethernet connectivity and Canbus interface for remote I/O with hardware in place to accept the Insight MCE motor controller.

The TMS 106 preferably includes a keypad to allow the operator to enter inputs. Preferably, the keypad includes function keys 106e, cursor keys (not shown) an enter key 106d, and a cancel key (not shown). A variety of displays may be used. It is contemplated that a gray scale LCD screen with back light and variable contrast control is sufficient.

The exemplary TMS 106 unit has lights 106b and 106c and the tool 104 contains an audible alarm device 104b for indications of faults, completions, unit ready conditions and the like. Optionally, the TMS 106 may be configured to drive remote (visible and/or audible) alarms.

The exemplary embodiment of the system contains one green light 106b, one red light 106c and a buzzer 104b on the tool. At various points in the cycle the following beep and light sequences are used:

Indicator Sequence (A) B PASS TORQUE: Buzzer on tool beeps one time for less than one second, green light turns on for less than one second.

Indicator Sequence (B) B SNUG WHEEL COMPLETE: Buzzer on tool beeps twice for less than one second each and the green light turns on for less than three seconds.

Indicator Sequence (C) B ERROR: four or more beeps less than a second each, red light turns on and stays on until successful tightening is completed or until error is resolved. Error message and possible methods to resolve the error displayed on the TMS screen.

Indicator Sequence (D) B WHEEL COMPLETE: one long beep for approximately 3 seconds, green light turns on for approximately five seconds.

Indicator Sequence (E) B VEHICLE COMPLETE: one long beep for approximately 3 seconds, green light turns on for approximately five seconds. Words "vehicle complete" shown on the TMS screen and graphic of a checkered flag displayed.

Other errors or indications:

- 5 1. Tool Calibration Fault - Red indicator 106b turns on and a message is displayed on the TMS screen if a tool calibration fault is detected.
2. When the TMS Controller 106 is initially powered on, the green indicator 106c lights up for an amount of time (Default value - 5 seconds).
- 10 3. When there is an error with data transmission to the DMS 110, the horn 104b sounds a beep (Default value - a single 5 second beep) and an error message is displayed.

Preferably, the TMS 106 is wired to the desired tool 104 through cable 108. The connection is used to drive and/or communicate with the horn 104b, the torque transducer 109, the calibration device memory 116, and an ambient temperature sensor contained in the memory chip 116. A single device, memory chip 116 can provide both the memory and temperature sensing functions. For example, a DS1624 Digital Thermometer and Memory device by Dallas Semiconductor of Dallas, TX may be used. Alternatively, a memory and a separate temperature sensor may be provided.

The TMS 106 is also wired to the air control system, regulator 103a, solenoid 103b and the pressure transducer (not shown) located inside the regulator through cable 107.

Preferably, the TMS 106 tracks the ambient temperature through memory / temperature sensor 116, and alters the torque algorithm used to achieve accurate torque control based on the temperature. Also, if the temperature falls outside of the tool's operating limits for accurate torque control, TMS 106 can prevent the tool 104 from operating.

Snugging:

Testing has determined that overall wheel 120 joint integrity is improved if the lug nuts 130 are "snugged" (pre-torqued to a very low torque setting) before the final tightening is completed. Snugging allows the wheel, hub and lug nuts 130 to align in the optimal location, minimizing stresses that are developed when all of the mechanical parts try to center themselves while one or more of the lug nuts 130 have already been fully tightened to the final torque value. To implement the snug feature, the TMS 106 sets the air pressure to a very low value. Each lug nut 130 is torqued to a low value (approximately 10 to 40 ft-lb). After each successful tightening, the buzzer 104b beeps, the number of lugs remaining to be snugged (displayed on the LCD 106a) is decremented by

one, and the green light 106b on the TMS 106 turns on for a short period of time. After all lug nuts 130 on a given wheel 120 have been snugged, the buzzer 104b sounds with a different tone and the air pressure is set to a final tightening pressure.

5 Note: If the nut 130 can not be snugged against the wheel 120 with a low, preset amount of torque, this might be an indication that the threads on the stud or nut are damaged. This feature gives visual feedback to the operator indicating that lug nuts 130 and or mounting studs should be replaced.

Final tightening:

10 After snugging, the operator is ready to complete the final tightening of each lug nut 130. The operator squeezes the trigger and the tool 104 begins to run. The tool 104 continues to run until the desired torque is achieved or until an error occurs. Note: Releasing the trigger prematurely results in a failed tightening cycle.

If the desired torque is achieved the following events occur:

1. TMS 106 turns off the air to the tool 104 by controlling the solenoid 103b.
- 15 2. Tool 104 shuts off.
3. The buzzer 104b on tool 104 produces one short beep.
4. The green pass light 106b on the control panel turns on for one second.
5. The torque value is displayed on the LCD display 106a labeled torque.
6. The counter on the LCD 106a showing the number of lugs remaining decreases by one.
- 20 7. Torque value is stored in memory of controller 106.
8. Graphics on the screen indicate the next lug to be tightened (star pattern).

After one second, the TMS 106 reactivates the solenoid 103b, and air is supplied to the tool 104 for the next cycle. The above cycle is repeated until all the lug nuts 130 on a given wheel 120 are successfully tightened. If all the lug nuts 130 on a wheel 120 have been successfully tightened to
25 the desired torque the following events occur:

- 1 TMS 106 turns off the air to the tool 104 by controlling the solenoid 103b
2. Tool 104 shuts off.
3. The buzzer 104b on the tool 104 produces a long beep.
4. The green "wheel complete" light 106b turns on for five seconds.

5. The message "Wheel Complete" flashes on the TMS screen.
6. The lug counter resets to the selected number and the unit 106 is ready for the next wheel 120.
7. The counter on the LCD 106a for the number of wheels 120 remaining decreases by one.

5 This cycle should continue until all lug nuts 130 for the entire car have been completed. After all the lug nuts 130 have been completed a "VEHICLE COMPLETE" message is printed to the LCD 106a and the data is automatically sent to the DMS 110 for electronic storage and printing. The shop supervisor reviews and signs the receipt verifying that the work order has been properly completed.

10 **Tightening Errors:**

In addition to monitoring the torque in the joint, system 100 also monitors other tightening parameters to verify that the tightening was correct. If any of the errors listed below are detected the following events occur:

1. TMS 106 turns off the air to the tool 104 by controlling the solenoid 103b
- 15 2. Tool 104 is shut off.
3. The air supply to the tool 104 remains off for an extended period of time so that the operator recognizes that the tightening was not completed correctly.
4. The buzzer 104b on the tool 104 produces four short beeps.
5. The red fail light 106c turns on and remains on until a successful tightening occurs.
- 20 6. The lug counter on the LCD 106 is not reduced by one.

Over torque / Under torque: If the actual torque measured deviates from the target torque range by more than an acceptable predetermined percent, for example, + / - 15% of the target torque, the fail light 106c is activated. The actual torque value is displayed on the LCD 106a. A message including corrective action is printed to the LCD to aid the operator in resolving the problem. A
25 typical error message may be "Over torque - Loosen and reapply lug nut 130."

Slow error: If the desired torque is not achieved within a preset number of impacts the fail light 106c is activated and the tool 104 is shut off. This type of error can occur if the threads on the lug nut 130 or stud are stripped. A message including corrective action is printed to the LCD 106a to aid the operator in resolving the problem.

Fast error: If the desired torque is achieved too quickly the system assumes that the lug that was just tightened was previously tightened to the desired torque. This feature prevents some lugs from being tightened more than once while others would not be tightened at all. A message including corrective action is printed to the LCD 106a to aid the operator in resolving the problem.

5 **System Diagnostics:**

Several system parameters are monitored to insure that the overall system is functioning properly. A pressure sensor is included in the system to monitor supply air pressure. If the target pressure drops below the predetermined value, the unit does not work. A pressure fail indicator is illuminated.

10 The TMS 106 monitors the condition of the strain gages 109 to determine if they are functioning within an acceptable range. The TMS 106 zeroes the strain gages 109 before each run to improve torque accuracy. If the strain gages 109 are determined to be damaged a calibration indicator is illuminated.

15 The number of cycles on each tool 104 is also monitored through the use of a "smart chip" 116 on each tool and recommendations on tool maintenance are supplied to the operator. The calibration data and current number of cycles run since last calibration are stored in the memory device 116. This data is uploaded to the TMS 106 when the tool 104 is first connected to the TMS. After each work order (car) is complete, TMS 106 updates the data in the chip 116 to maintain the total number of cycles. Based on the total number of cycles, the TMS determines when another
20 calibration is needed and notifies the user. TMS 106 may be programmed to prevent operation of the tool 104 if the calibration is out of date. Because the calibration data is stored on the tool 104, the tool can be shared between more than one TMS 106. The TMS 106 to which the tool 104 is connected at any given time can determine whether a new calibration is needed. Further, the service record for the tool may also be stored in the memory device 116.

25 The TMS 106 tracks the ambient temperature through a memory / temperature sensor 116, and alters the torque algorithm used to achieve accurate torque control based on the temperature. Also, if the temperature falls outside of the tool's operating limits for accurate torque control, TMS 106 can prevent the tool 104 from operating.

30 The TMS 106 also monitors the oil level in the inline lubricator to insure that the tool is lubricated according to design recommendations. If the lubricator does not contain oil an error indicator can be displayed on the TMS screen and operation of the tool can be prevented.

System operation:

FIGS. 2A-2H and 3A-3B show the program flow for the TMS 106 and the DMS 110 of an exemplary system 100. Reference is first made to FIGS. 3A and 3B, which show the operation of the DMS 110.

At step 300, executing a boot sequence starts up the DMS 110.

5 At step 301, a communications check is made by interrogating all of the connected TMS's 106 to determine which of the TMS's are active.

At step 302 the DMS determines if the boot sequence was successful. If the boot sequence was not completed and error message will be displayed 303.

10 At step 304, the main DMS display is presented. The Data Management System 110 captures the work order requirements using application specific software running in a Windows based environment, and displays the current job queue.

At step 305, the user interface of the DMS 110 guides the supervisor through the work-order data entry process. The supervisor typically enters a predetermined set of inputs for each automotive vehicle to be serviced. The shop supervisor inputs customer job information into the DMS 110.
15 Inputs to the DMS 110 may include such parameters as: Customer name, phone number, address, license plate number, make of car, model of car, option, year of production of car, color of car, number of tires being mounted, state or province. Some of the parameters may be optional (e.g., color of car); others may be mandatory (e.g., the number of tires to be mounted). The system administrator determines which parameters are optional and which are mandatory.

20 At step 306, if any required parameter is missing, the DMS 110 notifies the person entering the data to input the required information. Work order requirements may also come directly from the point of sales (POS) 112 in a variation of the system.

At step 307, the DMS 110 accesses the manufacturers' database to retrieve information on each vehicle in the job queue. Typically, the appropriate specifications are accessed by a database
25 query based on vehicle make, model, option and year. Based on the car's make, model, option and year of production, software in the DMS 110 determines the required lug nut torque specification and the number of lug nuts 130 on the vehicle, and includes this information in the work order

At step 308, a determination is made whether the required data is present in the manufacturers' database. As noted above, the data may be absent for brand new models.

30 At step 309, if the required data corresponding to a vehicle is not present in the manufacturers' database, the user is queried to enter the data manually.

At step 310, if any additional data is required, step 311 asks the operator if the job should be sent to the shop without all the required data. Step 309 can be repeated until all the required data is entered in the DMS 110.

At step 312, after all of the data is input to the DMS 110, the supervisor dispatches the request (e.g., by hitting the "enter" key) and the work order is sent to all the TMS controllers 106 in the shop. The information is downloaded to the TMS 106 via Ethernet 111 protocol.

At step 313, if the record (or dataset) is not downloaded successfully, then at step 314, the attempted transmission is repeated and an error message is displayed on the DMS 110. At step 315, with the job entered, the DMS job queue is displayed on the screen of DMS 110.

At step 316, when one of the TMS's 106 sends DMS 110 a message indicating that the TMS has chosen one of the jobs from the job queue to service, DMS 110 deletes that chosen job from the job queues of all of the remaining TMS's. This is accomplished by sending a message to each remaining TMS 106, commanding each remaining TMS to remove its respective copy of that job record. Alternatively, a replacement dataset may be sent to each remaining TMS 106, without the record corresponding to the chosen job.

At step 317, DMS 110 looks for a "job-complete" message from the TMS 106 that chose the job from the job queue. At step 318, if this message is not received at the DMS 110 from the TMS 106, then at step 319, the TMS 106 displays an error message. At step 320, when the "job-complete" message is received, the DMS 110 prints a hardcopy record of the job data. In one variation of the exemplary embodiment, the DMS 110 sends an interrogating message to the TMS 106 to request the status of the job. In an alternative variation, the DMS 110 waits passively for the "job-complete" message.

At step 321, the job completion information is also written to the DMS archive database of completed jobs.

At step 322, the DMS 110 returns to the main display.

FIGS. 2A-2H show the operation of one of the TMSs 106.

At step 200, the TMS 106 is powered on.

At step 201, the TMS 106 executes its boot sequence. The boot sequence includes the operating system launch of the TMS operating system, status checks, and the application launch. A communications check determines whether the communications link to the DMS 110 is operating properly. A tool check determines whether the TMS 106 is in communication with an attached tool

104 and with a properly configured memory device 116. The tool calibration data is also checked. The pressure in the airline 105 is checked. The transducer 109 of the tool 104 is checked and zeroed. The continuous lubricator oil level for the tool is checked.

At step 202, if the complete boot sequence is not completed properly, then at step 203, an
5 error message is provided, and step 201 is repeated.

At step 204, the TMS 106 requests and receives (from the DMS 110) the job queue data.

At step 205, the TMS accepts the DMS data (assuming the data is in the proper format).

At step 206, the job queue is displayed on the TMS display 106a.

At step 207, the operator can pick, from a job list on the TMS display 106a, the job
10 assignment matching the car in his service bay. At step 208, the TMS may be programmed to require the operator to provide authentication data, for example, by inputting an operator number.

At step 209, if the torque specification and number of lug nuts are not available in the file the TMS will request manual input 211 by the operator. At step 210, following successful selection of the job, TMS 106 sends an acknowledgment to DMS 110. The DMS 110 removes this job from all
15 the other TMS 106 units.

At step 212, the main screen is displayed and torque data, number of wheels, number of lugs etc. is displayed. The TMS 106 manages the tool functions required to complete the selected job.

At step 213, the exemplary system is programmed to require that the operator first snug the nuts 130 of the wheel 120 in place and then tighten each nut 130 of the wheel correctly before
20 moving to the next wheel. (An alternative system may be designed to omit the snugging step, but snugging is preferred, as explained above.)

In the snugging step, the controller sets the snug air pressure and tool torque, and the display enters the snug mode, to display snugging operation status. Throughout the operation, the lights 106b and 106c and the horn 104b provide indications of correct torque or error, as appropriate.

25 At step 214, the pressure in airline 105 is checked.

At step 215, if the pressure is not correct, then at step 216, the voltage provided to regulator 103 is adjusted.

At step 217, if the pressure cannot be adjusted to the desired level within a predetermined number of tries, then step 218 is executed, and an error message is provided.

At step 219, if the measured torque spike is not tightening "forward," then at step 220, the air pressure is increased to 90 pounds per square inch this will allow the operator to remove lug nuts that are already tightened.

At step 221, a check is made as to whether the tool 104 is pulsing in reverse. If not, then
5 control returns to step 213. If the tool 104 is pulsing in reverse, then at step 222, operation continues until the tool is not pulsing in reverse. If at step 219 the tool was pulsing in the forward direction then at step 223, the tool 104 runs until the desired torque is achieved.

At step 224, the tool is turned off for a predetermined period (e.g., 1 second) by turning off the air pressure to the tool by changing the state of solenoid 103b. Indicator sequence (A) is run to
10 give visual and audible indication of a successful tightening. At step 225, the count of remaining lug nuts 130 for the wheel 120 currently being mounted is reduced by one, and the air pressure is again turned on.

At step 226, if the number of lug nuts 130 completed is less than the total number of lug nuts 130 for the wheel 120 being mounted, then control returns to step 219. If the last lug nut 130 on the
15 wheel 120 is completed, then step 227 is executed.

At step 227, the appropriate visible and audible indicators, indicator sequence (B) are provided.

The TMS software uses the desired torque specification to reference an internal matrix of tool settings that are preset in the controller 106. The internal parameter matrix updates the algorithm to
20 produce optimal torque accuracy at each torque setting. For example, air pressure is one of the parameters set for each torque level. Adjusting air pressure for each desired torque greatly improves torque repeatability.

At step 228, the final torque specification and number of lug nuts is automatically entered into the algorithm.

25 At step 229, the mode displayed on the TMS is changed from "snug" to "final torque".

At step 230, the TMS 106 commands the regulator 103a (via line 107) to set the air pressure to its final predetermined value for tightening each lug nut 130 to the final desired torque.

At step 231, the TMS 106 checks whether the air pressure is set to the final preset pressure. If not, then at step 233, the air pressure is adjusted by sending a signal to regulator 103a via line 107,
30 and step 230 is repeated. At step 234, if the TMS 106 detects that a predetermined number of attempts have failed to achieve the desired final pressure, then an error condition is displayed.

At step 232, the TMS has configured the regulator for final tightening, and the operator can begin tightening lug nuts 130.

At step 235, if the torque spike is "forward," step 238 is executed next. If the torque spike is not "forward," then step 236 is executed. At step 236, the TMS 106 commands regulator 103a via
5 line 107 to set the air pressure to a predetermined maximum value (e.g., 90 psi). TMS 106 determines whether the tool 104 is still pulsing in reverse. If the tool is pulsing in reverse, then step 237 is executed and the TMS 106 continues monitoring until the tool stops pulsing in reverse, and control is transferred to step 230 (described above).

If the torque spike is forward at step 235, then at step 238, the TMS 106 determines whether
10 the desired torque was reached before the predetermined minimum number of blows. This could be an indication that the lug nut 130 was previously tightened or partially tightened. (In alternative embodiments using a non-impact tool, then an analogous check is made to determine whether the desired torque was reached in less than a predetermined minimum time.) If so, then at step 239, a fast error message is provided. A text message is displayed, Indicator sequence (C) is run and the
15 system goes to step 240 which turns the tool off for an extended period of time (4 seconds) to alert the operator that there was an error detected. 104b If the torque is not achieved in less than the minimum number of blows at step 238, then at step 241, TMS 106 determines whether the minimum target torque is equal to the actual torque. If not, then at step 242, TMS 106 determines whether the number of blows exceeds a preset number (for example 50). If the number of blows does not exceed
20 50, then the algorithm returns back to step 235. If the number of blows exceeds 50, then step 243 is executed. At step 243, the TMS 106 provides a slow error message. A text message is displayed, and indicator sequence (C) is run and the system goes to step 240 which turns the tool off for an extended period of time (4 seconds) to alert the operator that there was an error detected. 104b

If the minimum target torque equals the actual torque at step 241, then at step 244, the tool
25 104 is turned off for a predetermined period, such as one second.

At step 245, TMS 106 determines whether the actual torque is less than the required value. If so, then at step 246 TMS 106 provides an "under torque" message. A text message is displayed, and indicator sequence (C) is run and the system goes to step 240 which turns the tool off for an extended period of time (4 seconds) to alert the operator that there was an error detected. If the actual torque is
30 not less than the specified torque at step 245, then at step 247, TMS 106 determines whether the actual torque is greater than the specified value. If so, then at step 248, TMS 106 provides an "over torque" message. A text message is displayed, indicator sequence (C) is run and the system goes to

step 240 which turns the tool off for an extended period of time (4 seconds) to alert the operator that there was an error detected. If the actual torque is equal to the specified value at step 247, then at step 249, the lug nut 130 is completely tightened. The count of remaining lug nuts 130 to be tightened on the wheel 120 currently being mounted is decremented by 1. In addition, an indication
5 of a successfully completed lug nut 130 is provided. Indicator sequence (A) is run. Optionally, the actual torque value may be transmitted to the operator's screen.

At step 250, the TMS 106 determines whether the number of lug nuts 130 completed is equal to the full number of lug nuts on the wheel 120 being mounted. If not, then operation jumps to step 232 (FIG. 2D). If the full number of wheels 120 to be tightened have all been completed, then at
10 step 251, the count of remaining wheel 120 to be tightened is decremented by one, and Indicator sequence (D) is run. At step 253, the transducer is zeroed, to begin new data collection for the next wheel 120.

At step 252, TMS 106 determines whether the number of wheels 120 completed equals the full number of wheels 120 to be mounted. If not, then control jumps to step 213 (FIG. 2B). If,
15 however, all of the wheel 120 have been completed, step 254 is executed.

At step 254, the TMS 106 provides an indication that the job is complete. For example, a special message may be displayed to indicate completion of a job and indicator sequence (E) is run.

At step 255, the data collected during the job is transmitted to the DMS 110 for inclusion on the customer receipt. This data includes the actual torque recorded for each lug nut 130 of each
20 wheel 120. The exemplary TMS allows the system administrator to determine whether the data is automatically sent to the DMS 110 as soon as the last wheel 120 is complete, or an operator action (such as pressing the "enter" key) is required to initiate the transfer. The TMS 106 is then ready for the next job. At step 256, the data stored on chip 116 on the tool 104 is updated. For example, the total number of cycles performed by the tool 104 on the last vehicle may be written into chip 116.

25 At step 257, TMS 106 determines whether the number of cycles performed since the last calibration exceeds a calibration-warning limit for that given tool 104. Preferably, the calibration-warning limit is set below the absolute limit, and a warning is provided before the tool reaches its absolute limit. If the calibration-warning limit is exceeded, then at step 258, a message to that effect is displayed, both on the TMS 106 and the DMS 110.

30 At step 259, a warning is provided at the TMS before the absolute limit of cycles between calibrations is exceeded

At step 260, when the absolute limit of cycles between calibrations is reached, the TMS 106 automatically disables the tool 104. When this happens, the operator clears the screen and tags the tool data file to be sent to the DMS 110. At step 261, the operator clears the screen to send a tagged file to the DMS 110.

5 If, at step 257, the number of cycles since the last calibration does not exceed the calibration-warning limit, then at step 262, the TMS 106 determines whether the DMS 110 received the TMS data. If the data are not received, then at step 265, the TMS 106 retries (up to three times) to send the data to the DMS 110. At step 266, if the data are not received after three tries, then an error is indicated on the TMS.

10 At step 263, upon receipt of the data by the DMS 110, the DMS stores all the data in the DMS and prints a record of the tightening job.

At step 264, with the job completed, the screen again displays the job queue for selection of another job by the operator.

Reset Sequence:

15 Reference is now made to FIG. 2G. At any time during the wheel mounting procedure the operator might need to remove the wheel and start the process over. At step 267 the operator presses the reset key on the TMS 106. At step 268, the data from that wheel that has already been recorded is tagged and archived. Step 269 resets the lug counter back to the maximum for the wheel that is being worked on. The TMS will continue to run in normal mode at step 270.

20 Cancel Sequence:

Reference is now made to FIG. 2H. At any time during operation the operator might determine that a vehicle condition exists that can not be fixed at that time. In this case the operator might want to abort the job sequence and remove the car from the service bay. The operator can cancel a job at step 271 by pressing the "cancel" key. At step 272 a message is displayed asking the
25 operator if he/she is sure that the job should be canceled. If the operator presses "no" in step 273 then step 274 is executed and the TMS returns to the point in the job when the cancel button was pressed. If the operator chooses "yes" at step 273 the operator will be asked in step 275 if there are any remaining lug nuts that need to be tightened. If the operator chooses "no" in step 276 the system will send all the job data to the DMS with a note that the job has been canceled, step 277. The data
30 will be printed and filed. If the operator chooses "no" at step 276, then at step 278 the TMS will switch to final tightening mode. Air pressure will be set according to the pre-set torque specifications. Step 279 will record the torque of all lug nuts that are tightened. When the operator

is finished tightening all the lug nuts the enter key will be pressed at step 280. After the enter key is pressed in step 280 the TMS sends all the data to the DMS with a note that the job was canceled step 281.

Although the exemplary system uses pneumatically controlled discrete energy tools , the
5 DMS and TMS may be used to control other types of tools, such as DC electric powered tools for general industrial fastening, or any other air powered impact or clutch tools for automotive service or general industrial fastening.

Many elements of the present invention may be embodied in the form of computer-
implemented processes and apparatus for practicing those processes. These elements may also be
10 embodied in the form of computer program code embodied in tangible media, such as floppy diskettes, read only memories (ROMs), CD-ROMs, hard drives, high density disks, tape, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes an apparatus for practicing the invention. These elements of the present invention may also be embodied in the form of computer program code, for
15 example, whether stored in a storage medium, loaded into and/or executed by a computer, or transmitted over some transmission medium, such as over the electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into and executed by a processor, the processor becomes an apparatus for practicing the invention. When implemented on a general-purpose processor, the computer program code segments configure
20 the processor to create specific logic circuits.

Although the invention has been described in terms of exemplary embodiments, it is not limited thereto. Rather, the appended claim should be construed broadly, to include other variants and embodiments of the invention, which may be made by those skilled in the art without departing from the scope and range of equivalents of the invention.

25

What is claimed is:

- 1 1. A system for controlling a tool, comprising
2 at least one controller that controls the tool to apply a predetermined torque to each of a
3 plurality of fasteners sequentially; and
4 a processor, separate and distinct from the controller, the processor storing data including an
5 identification of the plurality of fasteners and the predetermined torque to be applied to the fasteners
6 by the tool, the processor providing the data to the at least one controller.
- 1 2. The system of claim 1, wherein:
2 the processor includes data associated with a plurality of objects, each object having a
3 respective plurality of fasteners, each plurality of fasteners having a respective predetermined
4 torque; and
5 the controller includes means for selecting one of the plurality of objects and for
6 downloading from the processor the identification of the plurality of fasteners and the
7 predetermined torque associated with the selected object.
- 1 3. The system of claim 1, wherein:
2 the processor includes data associated with a plurality of automobile models, each model
3 having a respective plurality of lug nuts, the data for each model including a number of lug nuts and
4 a predetermined torque.
- 1 4. The system of claim 1, wherein:
2 the controller receives sensor data from a sensor on the tool,
3 the controller uses the sensor data to control an amount of power provided to operate the
4 tool.
- 1 5. The system of claim 4, wherein the controller uses the sensor data to provide a visible or
2 audible signal that indicates whether the predetermined torque is applied to one of the fasteners
3 successfully.

1 6. The system of claim 5, wherein a visible or audible signal indicating unsuccessful
2 application of the predetermined torque continues until the predetermined torque is successfully
3 applied.

1 7. The system of claim 5, wherein a visible or audible signal indicates unsuccessful application
2 of the predetermined torque, if the sensor data indicates that an actual measured torque value differs
3 from the predetermined torque by a preset percentage. .

1 8. The system of claim 5, wherein the visible or audible signal indicates unsuccessful
2 application of the predetermined torque, if the predetermined torque is not achieved within a
3 maximum desired period of time or a maximum desired number of impacts by the tool.

1 9. The system of claim 5, wherein the visible or audible signal indicates unsuccessful
2 application of the predetermined torque, if the predetermined torque is achieved in less than a
3 minimum desired period of time or a minimum desired number of impacts of the tool.

1 10. The system of claim 1, wherein the controller causes the tool to apply a first predetermined
2 torque to all of the plurality of fasteners, and then apply a second predetermined torque to all of the
3 plurality of fasteners, wherein the second predetermined torque is a nominal target torque for each
4 of the fasteners, and the first predetermined torque is substantially less than the second
5 predetermined torque.

1 11. The system of claim 1, wherein:
2 the system manages a plurality of regulators, each regulator controlling an amount of power
3 supplied to a respectively different one of a plurality of tools; and
4 the at least one controller includes a plurality of controllers, each controlling a respective one of the
5 plurality of regulators so as to limit the power supplied to a corresponding one of the plurality of
6 tools to apply a predetermined torque to a respective plurality of fasteners.

1 12. The system of claim 1, wherein the controller includes a plurality of data that relate a desired
2 torque value with an input provided from the controller to a regulator, and
3 the regulator provides power to operate the tool, the data corresponding to the desired torque value.

1 13. The system of claim 12, wherein the processor includes data associated with a plurality of
2 objects, each object having a plurality of fasteners, each controller includes means for selecting one

3 of the plurality of objects and for downloading from the processor the identification of the plurality
4 of fasteners and the predetermined torque associated with the selected object.

1 14. The system of claim 13, wherein:

2 each controller includes a list of the plurality of objects, and

3 when one of the objects is selected by a first one of the controllers, that one object is
4 removed from the list of each other one of the plurality of controllers.

1 15. The system of claim 1, wherein:

2 the processor includes data associated with an automobile on which each wheel has a
3 respective plurality of lug nuts, the data including a number of lug nuts per wheel and a
4 predetermined torque;

5 the controller receives sensor data from a sensor on the tool; and

6 the controller uses the sensor data to provide a visible or audible signal that indicates
7 whether the predetermined torque is applied to each of the fasteners on a wheel of the automobile
8 successfully, for each wheel of the automobile being mounted.

1 16. The system of claim 15, wherein the controller includes:

2 means for receiving an operator-entered number of wheels to be mounted; and

3 means for providing a first type of visible or audible signal when all of the lug nuts of one of
4 the wheels to be mounted are successfully tightened; and

5 means for providing a second type of visible or audible signal when all of the wheels to be
6 mounted have been mounted and the corresponding lug nuts thereof have all been tightened.

1 17. A system for applying fasteners, comprising:

2 a plurality of tools, each capable of applying torque to a respective plurality of fasteners;

3 a plurality of power sources for operating corresponding ones of the plurality of tools;

4 a plurality of regulators, each regulator controlling an amount of power supplied by a
5 respectively different one of the power sources to a corresponding one of the plurality of tools;

6 a plurality of controllers, each controlling a respective one of the plurality of regulators so as
7 to supply power to a corresponding one of the plurality of tools to apply a predetermined torque to a
8 respective plurality of fasteners; and

9 a processor, separate and distinct from the plurality of controllers, the processor storing data
10 including an identification of each plurality of fasteners and the corresponding predetermined
11 torque to be applied to each plurality of fasteners by the corresponding tool, the processor providing
12 the identification data to each of the plurality of controllers.

1 18. The system of claim 17, wherein at least one of the tools has a memory device thereon, the
2 memory device storing at least one of the group consisting of calibration data for the tool, a total
3 number of cycles of the tool that are run, and documentation of service performed on the tool.

1 19. The system of claim 18, wherein the processor determines when the at least one tool is to be
2 calibrated, based on the total number of cycles stored in the memory device.

1 20. The system of claim 17, wherein the processor includes

2 means for monitoring at least one parameter of at least one of the tools, the at least one
3 parameter being selected from the group consisting of air pressure, ambient temperature, and
4 lubricant supply; and

5 means for providing a visible or audible warning if the value of the monitored parameter
6 falls outside a predetermined range.

1 21. The system of claim 17, wherein the processor includes means for receiving and storing
2 torque values from each of the fasteners tightened by one of the tools, and a list of any errors that
3 occur during use of the tool.

1 22. A method for applying a respective plurality of fasteners to each of a plurality of objects,
2 comprising the steps of:

3 electronically controlling a plurality of regulators, each regulator controlling an amount of
4 power supplied to a corresponding tool to apply a corresponding predetermined torque to a
5 respective plurality of fasteners;

6 storing data in a single computer, the data including an identification of each plurality of
7 fasteners and the corresponding predetermined torque to be applied to each plurality of fasteners by
8 the corresponding tool; and

9 providing a list of the objects from the computer to each of a plurality of controllers, each
10 controller operating a respective one of the regulators.

1 23. The method of claim 22, further comprising:

2 selecting one of the objects from one of the controllers;

3 downloading the data corresponding to the selected object from the computer to the one of
4 the controllers; and

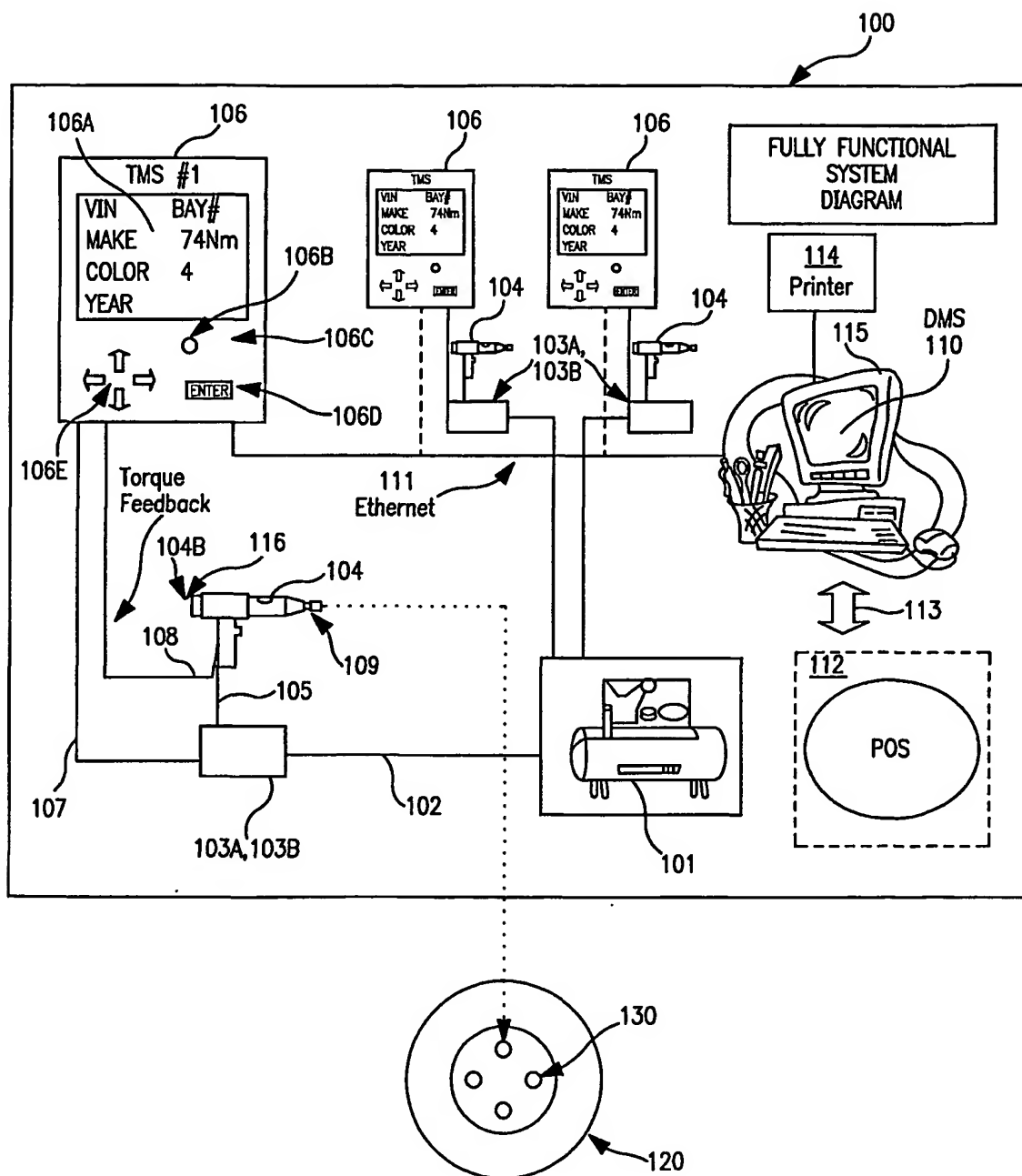
5 removing the selected object from the list in each of the controllers other than the controller
6 from which the one object is selected.

1 24. The method of claim 23, further comprising:

2 applying the predetermined torque to each of the plurality of fasteners on the selected object;
3 and

4 automatically generating a visible or audible signal when the predetermined torque is
5 successfully applied to any of the plurality of fasteners.

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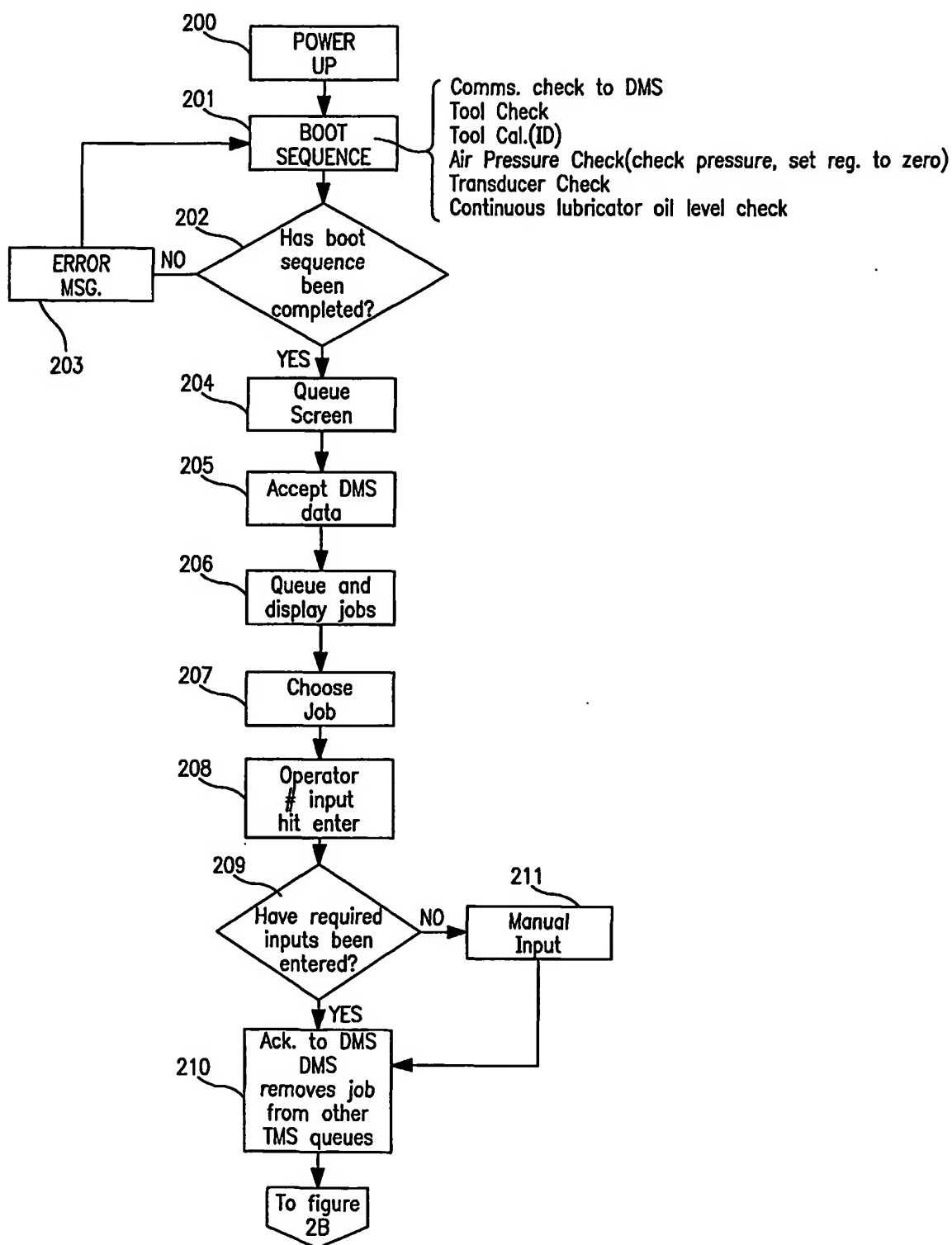


FIG. 2A

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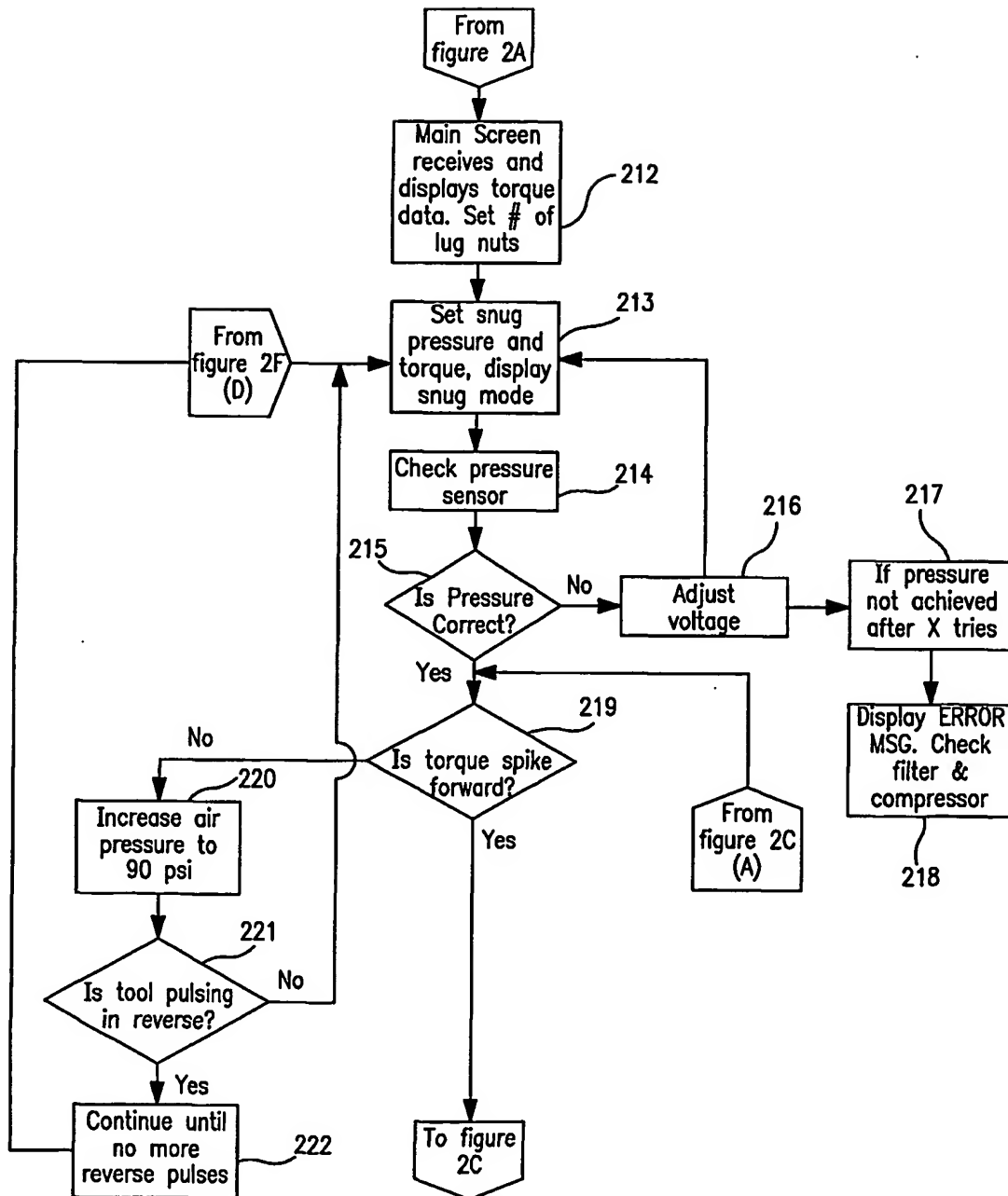


FIG. 2B

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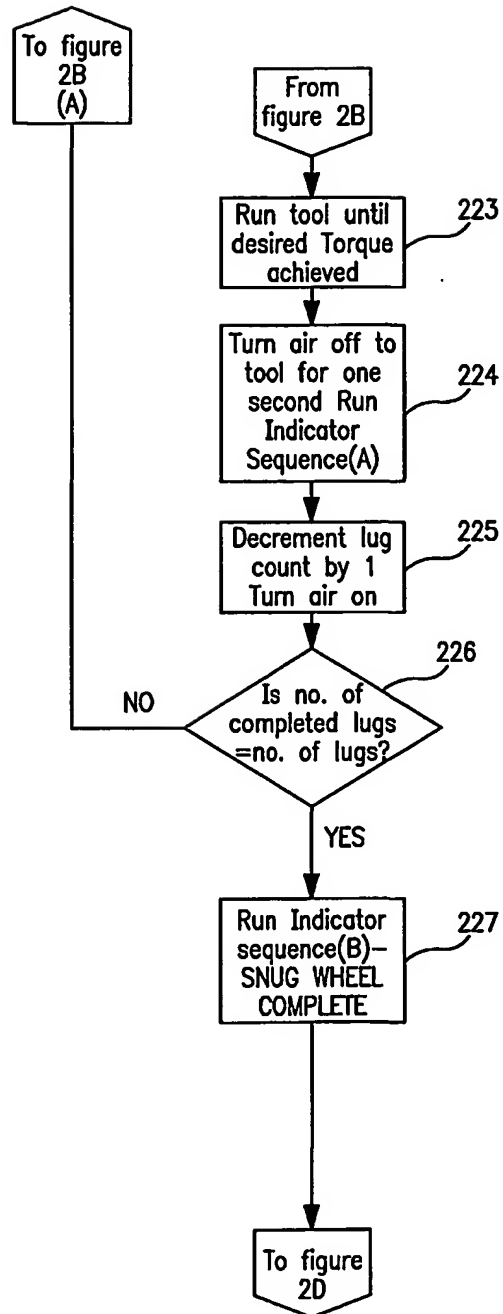


FIG. 2C

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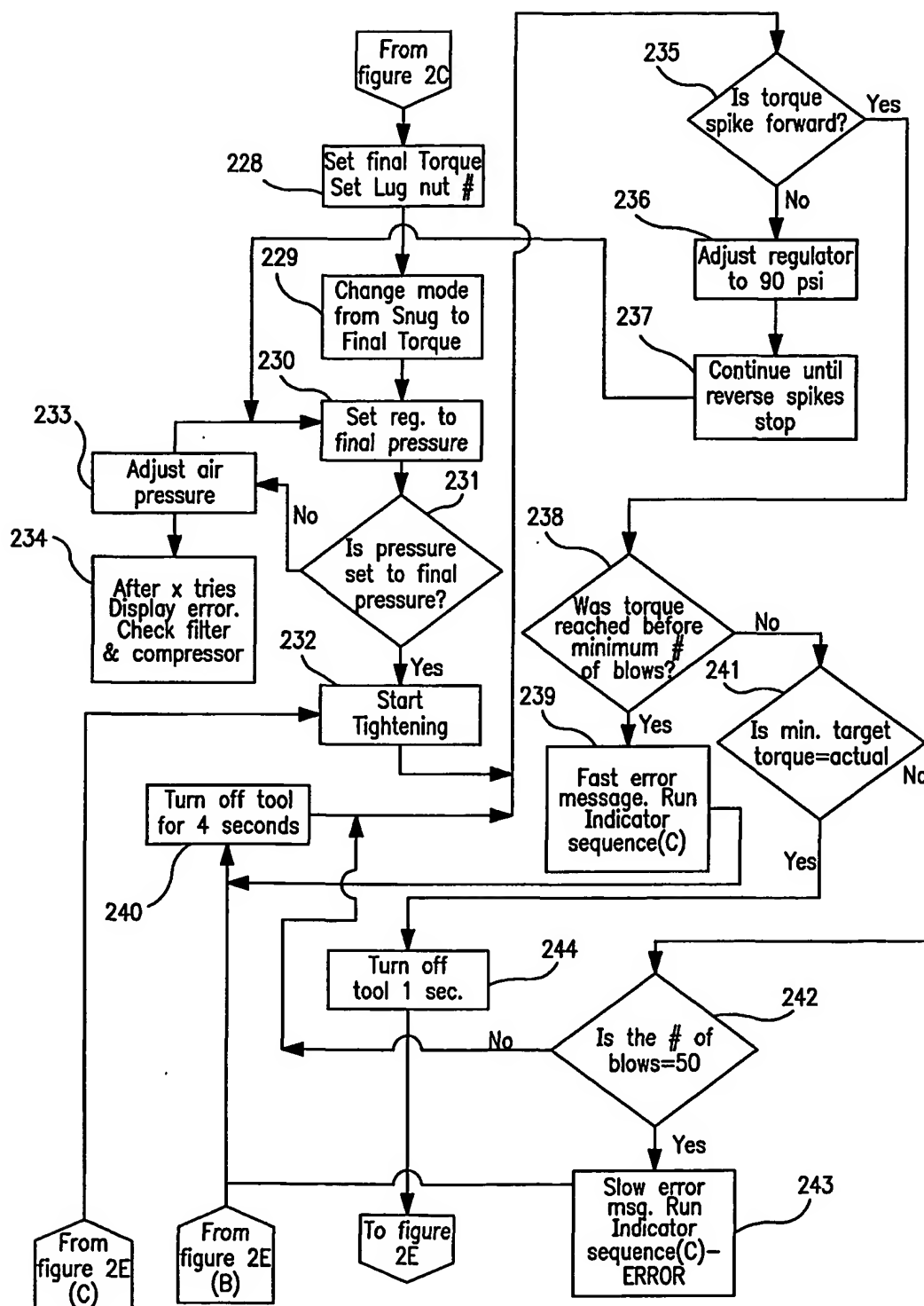


FIG. 2D

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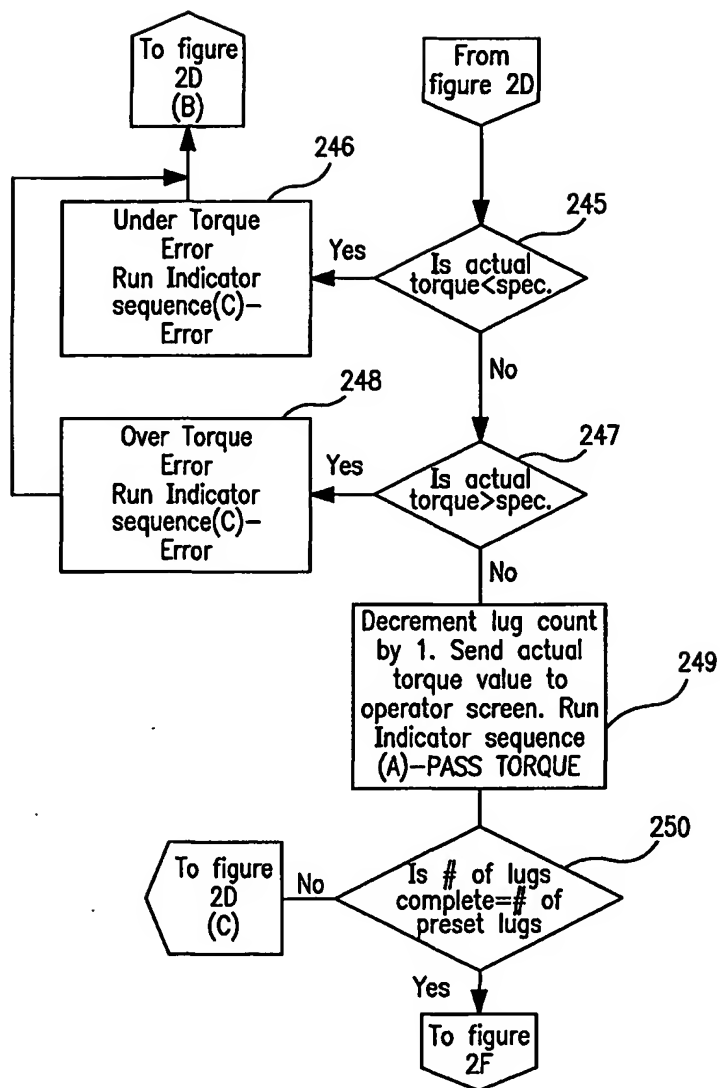


FIG. 2E

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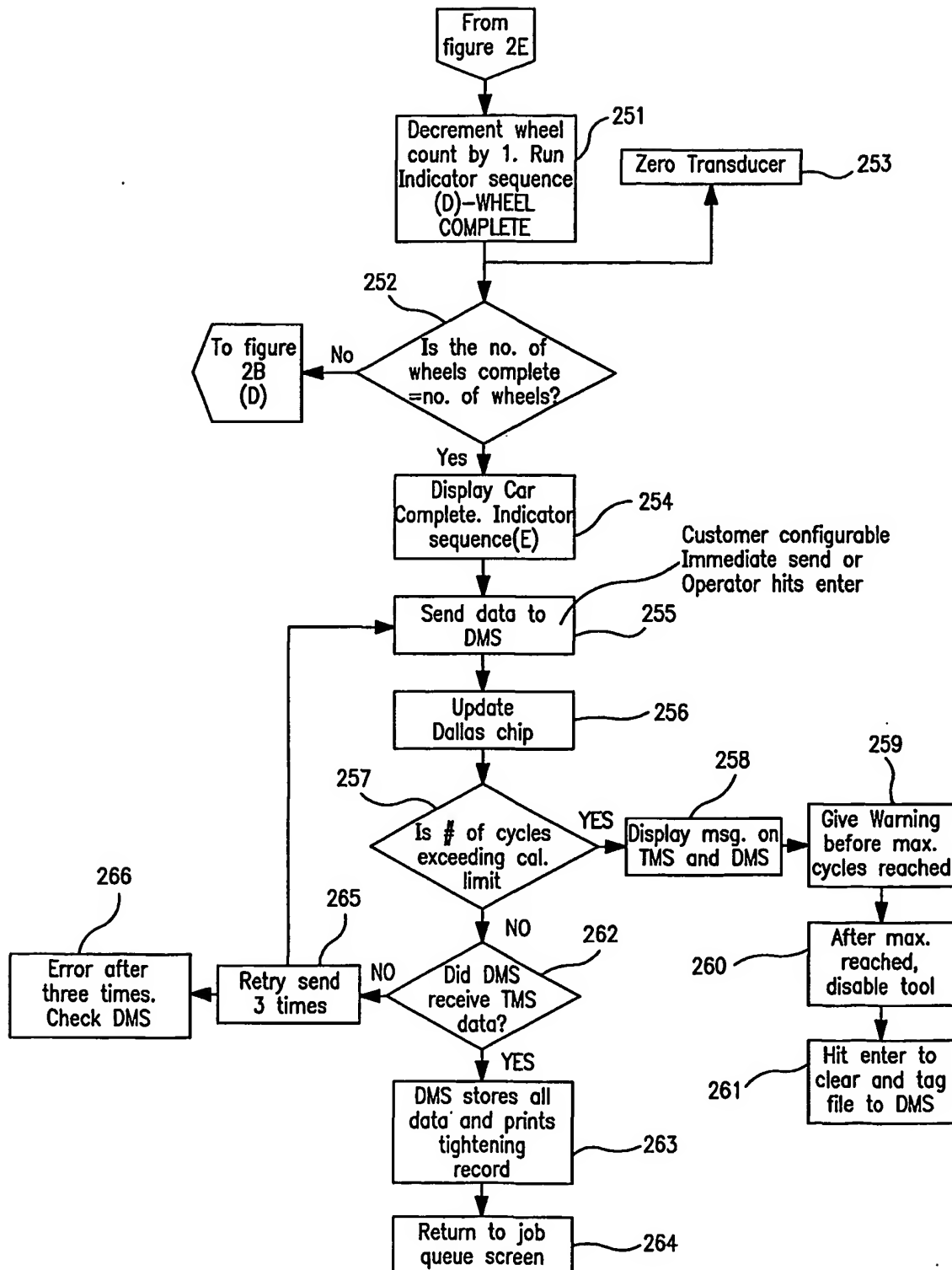


FIG. 2F

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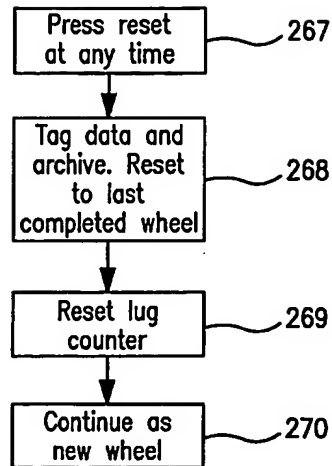


FIG. 2G

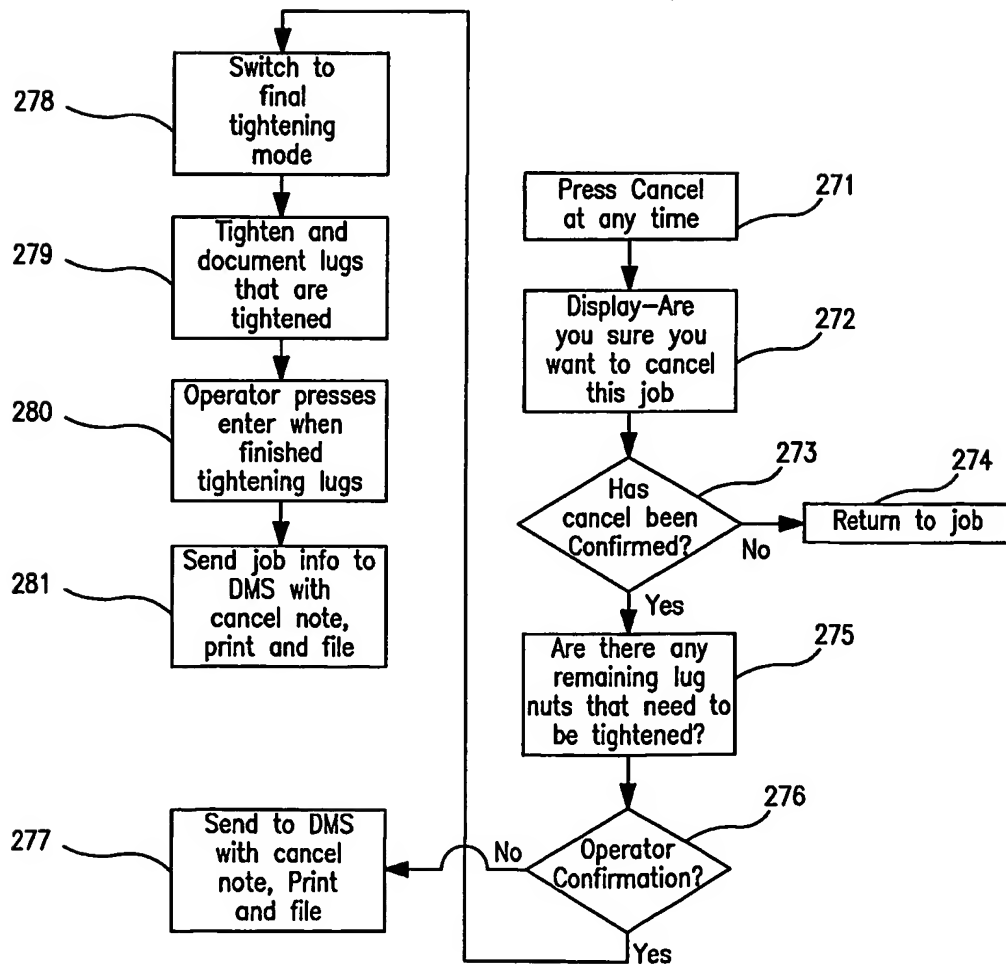


FIG. 2H

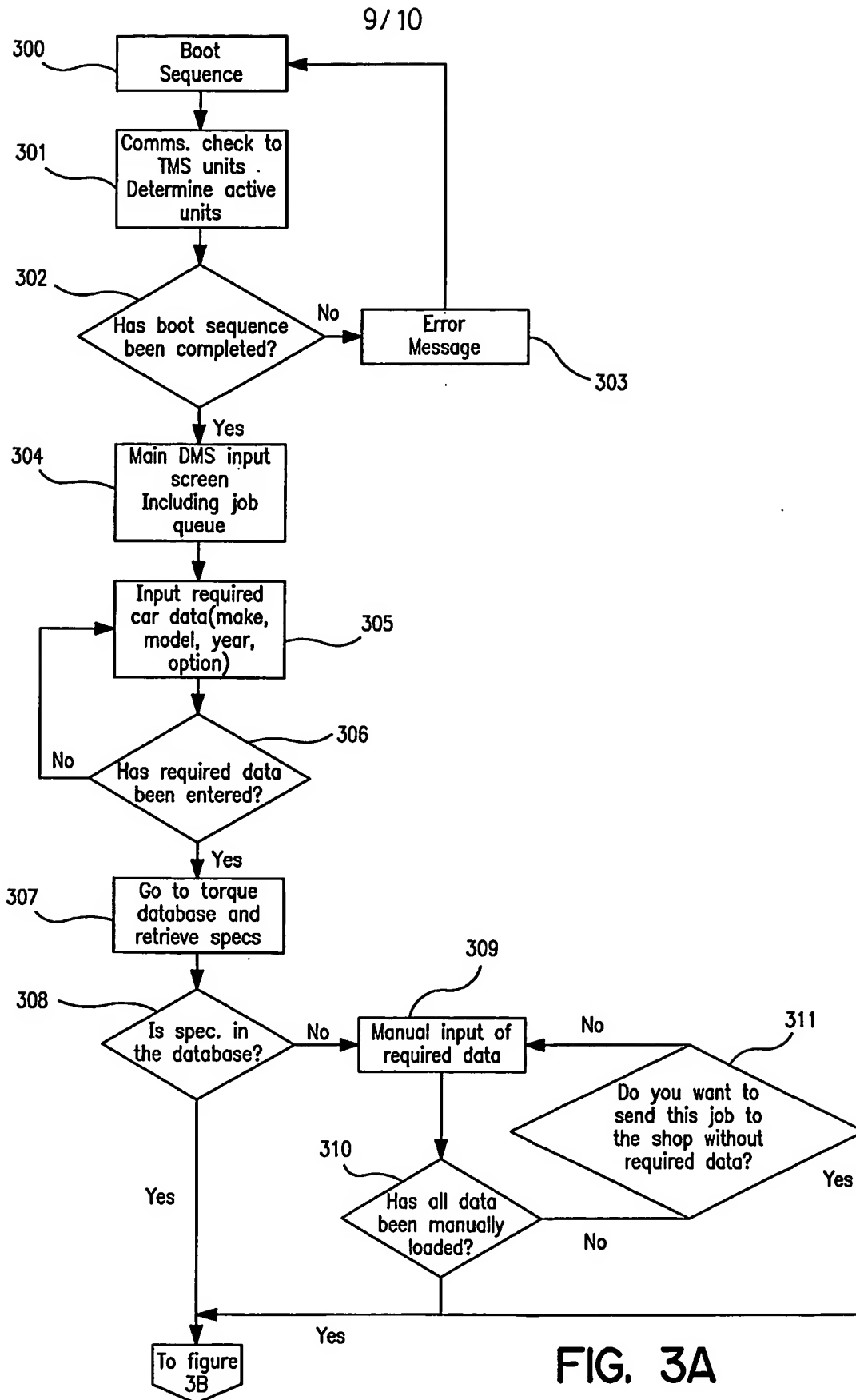


FIG. 3A

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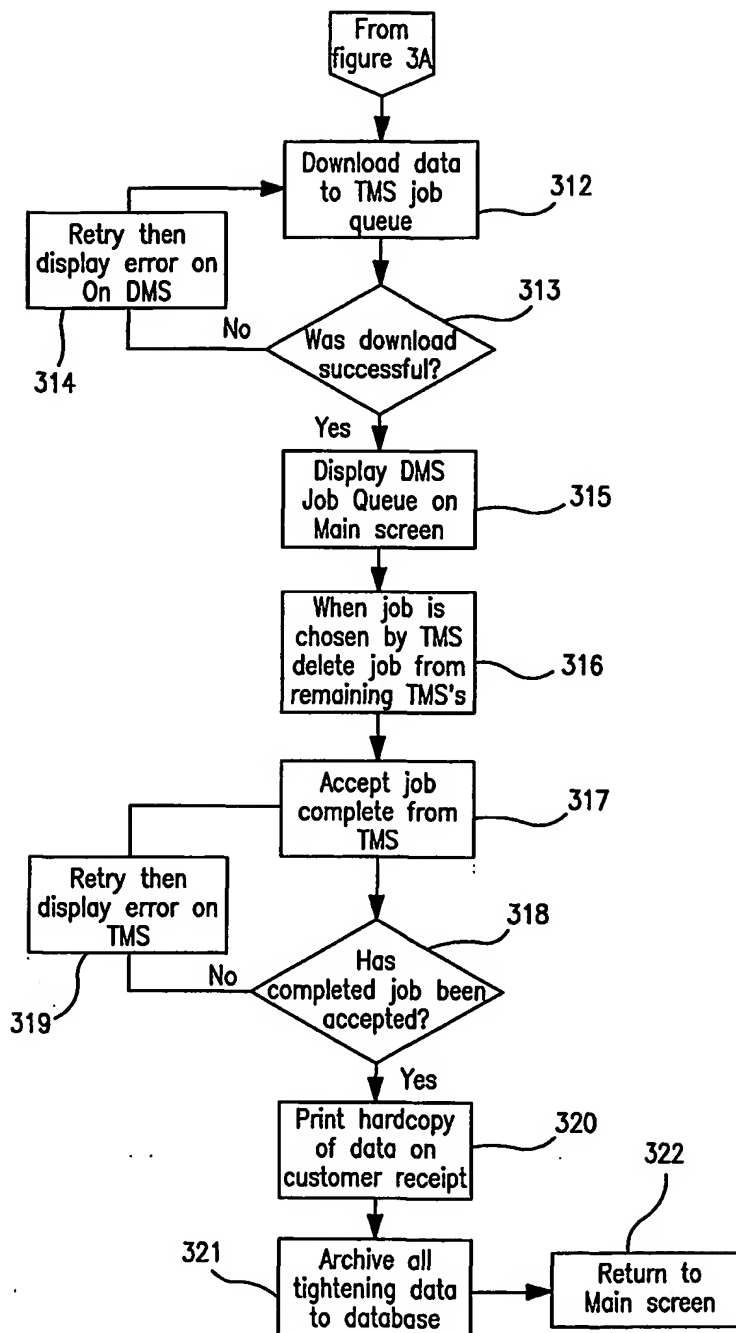


FIG. 3B

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